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PRACTICAL

DYNAMO-BUILDING

FOR AMATEURS.

BY

FREDERICK W. WALKER,

M.E.

WITH NUMEROUS ILLUSTRATIONS.

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PRACTICAL DYNAMO-BUILDING FOR AMATEURS.

INTRODUCTION.

Of the mighty army of scientific amateurs there are thousands who would like to construct a practical dynamo, and thousands who have already made a small one, and are desirous of extending their practice with a larger machine. There are many instances where the amateur electrician has every facility, every convenience and tools at hand, wherewith to construct a dynamo and its necessary adjuncts, that will afford him 50 incandescence, or one 20,000-c.p. arc lamp at will, with the same winding. Take, for example, an engineer in charge of the machinery in a large works: he has his forge, turnery, vice-bench and pattern shop, and given a rudimentary knowledge of the principles of electric lighting, and the necessary instructions, there is no reason why he should not at once gratify his own inclinations, and give his employer the benefit of the electric light. In the present series of articles the use of engineer's tools, and also a fair groundwork in the theory of electricity, including Ohm's law, is premised by the author.

In the little dynamo here described and illustrated, the field-magnets consist of simple soft cast iron, not from preference, but because such material is far easier for the amateur to fit up, than the more expensive and troublesome forgings, which can rarely be obtained to correspond unless made from a die.

On the other hand, the armature consists of a series of links, each forming the segment of a circle made of best charcoal sheet-iron, and insulated in a manner to be described afterwards, so that the "eddy" or Foucault currents are retarded, and their perceptible effect diminished as much as possible.

Such a dynamo machine requires in its construction no particular skill beyond that which every true mechanic must have attained before he can be worthy of the name: care and accuracy, combined with judgment, will insure success. The lathe, if a good 8in. surfacing screw-cutting, with gap bed to take a radius of 1ft. 6in., will suffice to do all the work that requires a power-tool. Here the amateur dynamo manufacturer may drill the field magnet castings, turn the spindle, armature ends, and commutator, and bore the poles if it be necessary. With the same tool he may wind the field bobbins, and bind the armature; in short, every operation may easily be performed upon such a lathe, and good work be turned out with it as the only tool; yet where a separate drilling and planing machine is in use, the advantages in favour of the amateur are greater.

No father can be prouder of his firstborn than that amateur whose brow has been touched with the divine fire of genius is of his first practical dynamo. How he watches the thin phosphorescent line that intervenes between the brush and the commutator, and is the visible sign of an actual current that in flowing round the magnet coils shall so augment itself as to develop light, heat, or power in an exterior circuit.

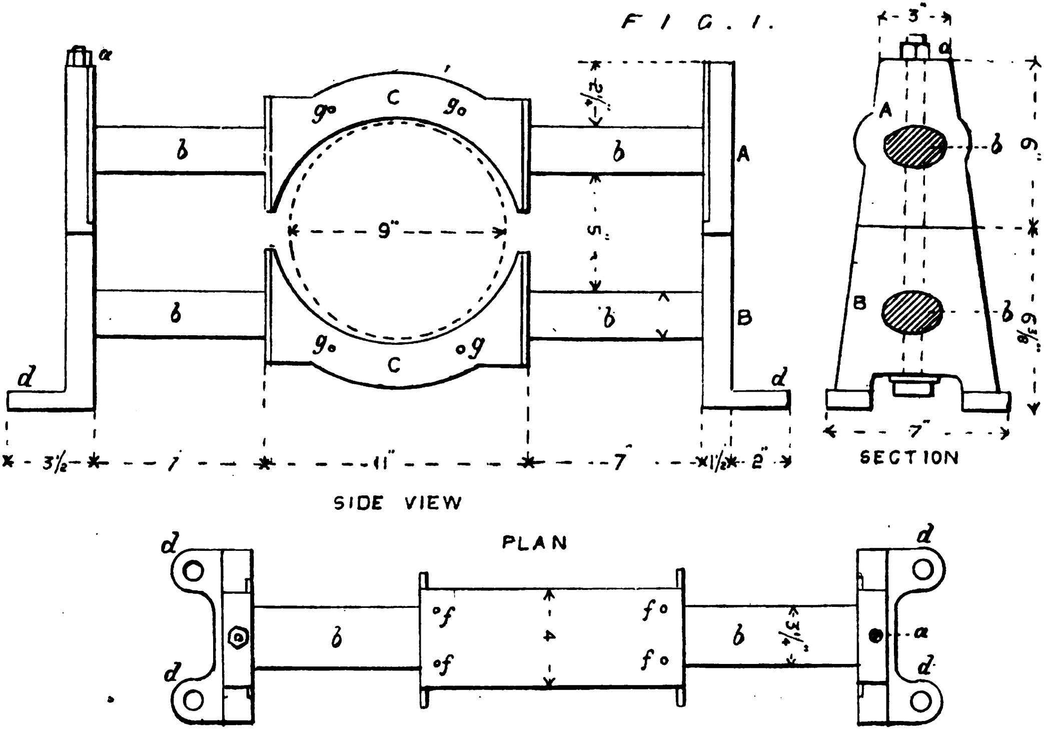
Using the same castings and armature, but differently wound, the same dynamo may be made to give different values of currents and electromotive force, and it is the writer's intention to give practical instructions upon such winding for the convenience of the amateur, so as to meet his requirements within the range of the machine.

FIELD MAGNETS.

The field magnets, as illustrated in Fig. 1, are of cast iron, in two pieces, A and B, which are bolted together by the bolts *a a*, which should be turned to fit the holes fairly well, so that there should be no rock or tendency to shifting when the machine is fitted up. The cores of the magnets *b* are oval in section, in order that the wire should not be strained in winding, as it would over a flat core with rounded ends. The patterns should be carefully constructed so as to minimise the tooling and fitting, and when this is done it should not be necessary to bore out the pole pieces *c*. This bore is not circular, but, as is plainly shown in the drawing, chamfered off toward the edges of the pole pieces, the armature being represented by the dotted line. The feet *d* of the dynamo may have the holes cast in, and for that purpose prints must be attached to the pattern for ¾in. clearing holes. The projections *e*, which are cast on the magnets, form bobbin ends, for the proper winding and protection of the wire.

The holes for the bolts *a* may also be cast in, and subsequently cleaned out by a bit; but if the tools at the command of the amateur should allow of it, it is preferable to drill these holes ¾in. and fit the bolts *a* to them. The holes marked *f* upon the plan, Fig. 1, are ⅜in. tapping, and serve for attaching the terminal board, to be described afterwards. The ½in. tapping holes *g*, shown in the side elevation in Fig. 1, must be marked off after the bearing ends are fitted. The surface of the joint *h h'* between the two halves of the field magnets should be planed, or chipped and filed, so that the polar bore is parallel, and of exactly the right diameter when the whole is fitted together; therefore, to enable this to be done, the pattern should have a piece of millboard, or thin wood glued upon it, of a thickness that will enable a good well-fitting sur-

FIG. 1.


a
b
b
b
b
C
C
g
g
g
g
A
B
d
d
9"
5"
2¼"
3½
7
11"
7
1½
2"
SIDE VIEW
3"
a
A
b
B
b
6"
6⅜"
7"
SECTION
PLAN
d
d
d
d
b
b
f
f
f
f
4
3¼"
a

face to be obtained by planing, or chipping and filing. If a planing machine is available, a cut may be taken over the feet *d*, and so provide a true base for bolting the dynamo upon its foundation when finished.

Each half of the magnets must now be centred, so that the cores *b* may run tolerably true in the lathe, these centres being drilled and counter-sunk, so as to allow of the strain of winding without accidents, and the two halves then bolted together, may be placed aside, ready for the bearing ends to be fitted.

All the sizes are carefully marked upon the drawings throughout, so that these do not require recapitulation here.

The bearing ends, Fig. 2, are to be cast in gun-metal, and, as will be seen, are designed so as to allow a long bearing surface, and also afford a support for the pole pieces, rendering the whole mass perfectly rigid when bolted together.

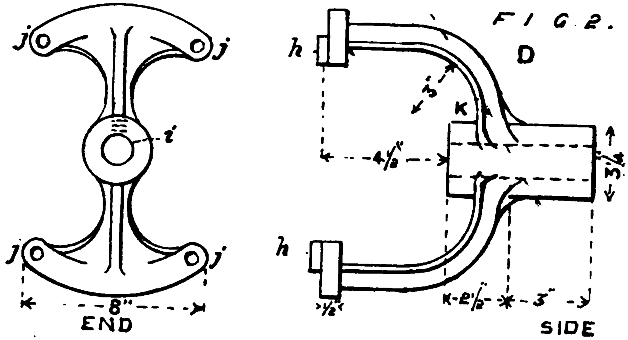
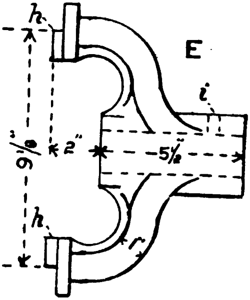


FIG. 2.

END SIDE

A fillet, at *h*, is cast upon the flange of a diameter, to allow of turning up to fit the polar bore tightly, and the whole is as light as the weight and strain that is imposed upon it will permit.

One of these bearing ends, D, is elongated as shown, to allow of the commutator and brush-holder. This one is fixed to the face-plate by the flange, and bored out to 1in., smooth and parallel. Then, driving it upon a mandrel, the boss may be skinned and faced, the inner portion *k* turned to fit the bore of the brush-holder, then the flange may be faced, and the fillet *h* turned to fit the poles. The holes *j* are drilled, ¼in. clearing, and one ⅜in. tapping in the boss, shown dotted at *i*, to receive the lubricator. The bearing end E is similarly bored out 1¼in., and turned, faced, and drilled in the same manner, and then both ends may be put in position, and the holes *g* in the pole-pieces drilled and tapped, and the ¼in. set screws fitted, ready for permanent fitting up. If the pole-pieces have been bored out, it is fair to suppose that the end-pieces have been faced also, in which case the bearing ends will not require any adjusting, but their respective bores be opposite, and be parallel to a common centre line, and not cause the spindle to bind.



However, if, on the contrary, the poles have not been bored, the faces will require a little fitting before the spindle will run freely, and in this case it will be better to wait until the latter is turned before adjusting the bearing ends.

The next portion of the dynamo that claims attention is the two gun-metal wheel-ends for supporting the armature ring.

These are shown in front and side elevation by Fig. 3, and the pattern is sufficiently simple in construction as to require no explanation beyond the drawing. These wheel-ends are bored out 1½in., and turned bright all over, with a parallel feather-way cut in the one nearest the commutator, and a keyway in the opposite one. It is extremely important that these keyways should be coincident, that designed for the feather being ¼in. square, and the other ⅜in. by $\frac{5}{16}$in., as shown. A centre being fixed in the bore of each wheel-end, a circle must be marked with the compasses 6¾in. in diameter, and this carefully and accurately divided into six parts, which will form the centres for six ¼in. clearing holes.

The marking and drilling of these holes must be performed with the utmost care, or the subsequent building-up of the armature will be distorted, and it will never run true, which is a fatal error in dynamo manufacture, since the shifting of the centres of force in an unbalanced armature frequently leads to its total destruction.

SPINDLE.

A good piece of mild steel of even grain must now be chosen for the armature spindle (Fig. 4), which must be turned to fit the bearing ends D at *k* and *k'* respectively, the wheel-ends also being a good fit at *l* and *l'*. The screw-thread, *m m*, may be of any convenient fine pitch, say 12 to the inch, and the steel hexagon nuts, *n n*, faced up perfectly true, and slightly hollow on the inner face.

The keyway (flat) at *l*, and the sunk feather at *l'* may now be finished, and the wheel-ends tried thereon, so that the six small holes around the latter may be exactly opposite when the ends are firmly keyed up to their proper distance apart, viz., 5″.

ARMATURE CORE.

The next operation will be the building-up, insulating, and winding of the armature. Two rings of 3/16in. sheet iron (Fig. 4) are cut out, turned and faced perfectly true on both sides, the diameters, outer and inner respectively, being turned to the *exact* size specified upon the drawing. These rings are marked off for six ⅜in. holes, to coincide perfectly with the ¼in. holes that have already been drilled in the wheel ends. The slightest deviation from perfect accuracy in drilling and marking off any of these holes will certainly insure failure in the armature.

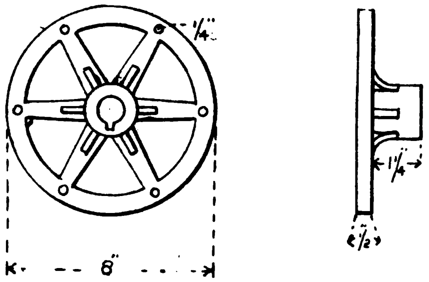
The six holes in each ring should then be plugged with plugs of vulcanised fibre or boxwood, and again marked off, and the plugs drilled ¼in. clearing.

It will be noticed in Fig. 3 that one edge of the rings is well rounded, so that a sharp edge is not presented to the wire, which would tend to cut and destroy insulation. Six pieces of drawn iron wire, No. 4 B.W.G., should now be cut off, 10in. long, and screwed at each end to a distance of 3½in., leaving 3½in. plain in the centre. Small gun-metal hexagon nuts should be fitted to each end of these studs, and it will be advisable at this stage to make a plate spanner to fit them. Twelve small gun-metal ferrules are then prepared, Fig. 5, drilled out to ¼in. clearing, and turned and faced as shown.

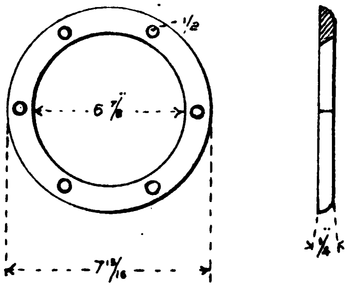
It is necessary now to prepare the charcoal iron segments which are to form the armature core. Fig. 6 represents one of these segments, half-size, and the gauge of the sheet iron out of which they are stamped or cut is No. 20.

In the construction of the present armature about 240 segments will be required; therefore it will hardly be worth while for the amateur to make his own dies when the punchings are to be had very cheaply—about 4s. per gross.

The next step towards the building-up of the armature is to

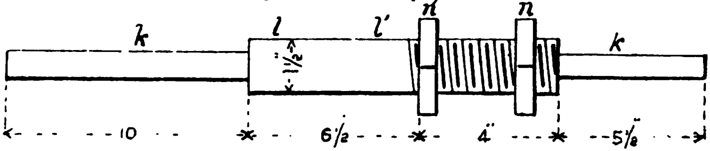


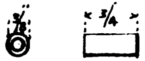
G M WHEEL ENDS (2)
FIG 3



W I RING (2)
FIG 4

STEEL SPINDLE (1)





G.M FERRULE (12)
FIG 5

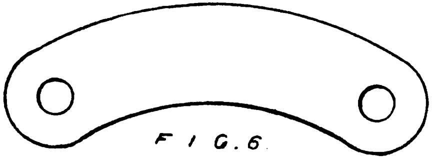


FIG. 6
HALF SIZE

cut out 60 discs of paper, exactly to the wrought-iron rings, as shown in Fig. 4. The holes may be then punched by an ordinary belt-mender's punch upon a block of hard wood. The paper discs must be painted on both sides with shellac varnish (spirit), and hung up to dry. The sheet-iron segments should also receive a coat of Brunswick black by warming and dipping, and then laid aside to dry.

The six studs must now be taped with two layers of tape, well painted with shellac, and the ends fastened with Prout's elastic glue. This taping, however, is confined to the 3½in. of the plain portion of the studs. One of the wrought-iron rings, with its insulating bushes, is now threaded upon the six studs, and the ferrules before-mentioned next, and then the nuts, leaving the other end of the studs free for building up.

A piece of board should have six holes bored in it to coincide with the studs, and their lower ends, projecting beyond the nuts, be placed therein, so as to keep the free ends in place and tolerably rigid. After painting the inner surface of the ring with the aforesaid shellac varnish (which should be kept in hand, being constantly in requisition), two of the paper discs

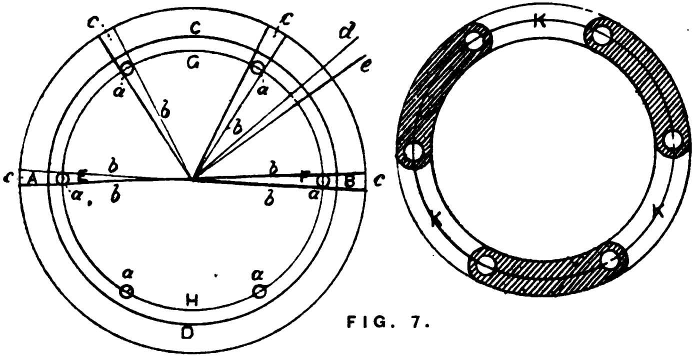


FIG. 7.

may be slipped over the studs, and pressed upon the wet shellac. Three segments must be threaded upon the studs, as shown by the lighter shaded portion K in Fig. 7, missing a space between each, then the next three, indicated by the dark shade upon the alternate studs.

This constitutes one layer, and the order of building should not on any account be deviated from, lest the armature should be irregular in form when finished. Each four layers should receive a coat of shellac and two discs of paper before again commencing to build. 13

When 220 segments have been thus built up, two discs of paper must precede the wrought-iron ring, the rounded edges of which should be placed outwards. The remaining six ferrules may now be threaded upon the studs, and the whole screwed up by the plate-spanner, a few turns at a time to each nut, until the whole mass is rigid, and 4⅛in. in length.

It will be wise at this stage to allow the core to dry, either in front of an open fire, or upon a steam boiler—the latter method being preferable where practicable, because the heat is uniform.

The insulation of the sections of the core can now be tested by a small battery and detector galvanometer; but if the instructions relating to the building and insulating are carefully carried out, the result cannot fail to be satisfactory.

The operation of taping is the next that has to be performed, and this is done by wrapping the tape tightly in a longitudinal direction, over and under alternately, until the whole core is covered, except the spaces left by the projecting ferrules. Shorter lengths of tape are attached by shellac across these gaps, and the ferrules themselves taped around. Two layers of tape will be found sufficient; then the whole should be saturated with shellac varnish and laid aside to dry.

CHAPTER II.

WINDING.

Before dealing with the subject of winding the armature in question, it will be well to consider for what purpose the dynamo is required—whether for arc-lighting, incandescent lamps, or for charging accumulators. For the first case, if it be required to work two arc lamps in "series," the E.M.F. at the terminal must be 110 volts, and the current flowing through the total resistance of the electrical circuit nine ampères, showing that this total resistance R by Ohm's law, thus, $R = E/C$, is equal to the quotient obtained by dividing the electromotive force in volts E by the current in ampères C, therefore, $110/9 = 12{\cdot}2$ ohms. The resistance R includes the resistance of arc, series coil, or solenoid upon the lamp, leads, and the resistance of the armature between the brushes. In the cases of "series," or "shunt"-wound field magnets, this effective resistance R is increased or diminished respectively; but that must be dealt with in due time. Therefore, in considering the winding of the armature, the external known resistance must be taken, R, and the resistance of the dynamo r approximated, as it is yet unknown. Then, from the equation, $C \times R + r = E$, the required electromotive force is known, and must be provided for by a certain length of insulated wire, to be wrapped upon the core.

The electromotive force of any machine depends upon—

I. The strength of the magnetic field.

II. The rate of speed at which the conductor passes through the field.

III. The length of such conductor.

Now, the former may be varied by suitable arrangement of the field magnets; they may be more massive, and possess larger coils in one case than in another, or, in fact, when the cores of the field magnets are made of wrought iron, the efficiency of the magnetic field, in comparison with the current energy absorbed by its maintenance, is from 20 to 30 per cent. greater than is the case with a cast-iron field. Such wrought-iron cores and pole-pieces are, however, very difficult of construction without proper tools and contrivances, which are beyond the reach of most amateurs; but for the especial benefit of those who desire to profit by the increased efficiency ot wrought-iron cores, we shall afterwards describe such a set of field magnets to suit the present form of armature.

The rate of speed at which the conductor passes through the field is dependent alike upon the diameter of the armature and the speed at which its spindle is driven.

The length of the conductor per volt of electromotive force varies according to the conditions enumerated above; recent improvements in dynamo-machines by the best makers have limited it to three-quarter yard per volt.

Such machines, however, are not practicable for amateur construction, for advantage is taken of the fact that the nearer the iron core of the armature can be brought to the poles the greater the efficiency. Since this entails a large diameter, and corresponding field magnets, in order to get the requisite length of conductor in as few layers as possible, a certain loss of efficiency per weight of copper is unavoidable.

We must establish a length of wire per volt that will give the required effect upon this and similar dynamos; this deduced from actual experience in the construction of several machines of this type, of different sizes and output, all of which have given the calculated E.M.F. and current through the stipulated resistance, when worked. This length may be stated as three yards per volt, or its speed equivalent in the present instance 5,850 yards per second, giving a speed of 1,300 per minute, which is not excessive for a small machine.

Then, returning to the calculation of winding for 110 volts and nine ampères through a total R of 12·2 ohms, the length of wire required for the armature conductor will be 110 × 3 = 330 yards, and since the commutator is to have 48 or 36 divisions, or plates, preferably the former; 330/48 = 6·8 is the number of yards in each coil.

A circle, A B C D, should now be drawn upon paper, Fig. 7, equal in diameter to the taped armature core, with an inner circle, E F G H, corresponding to the centres of the stud holes. The latter being divided into six parts, the six ferrules should be lined out thereon, as small circles *a a a a a a*. An outer circle, ⅛in. less in diameter than the bore of the pole-pieces, will represent the extreme diameter of the wire when wound. Radial lines *b′ b′ b b* will indicate the spaces *c c c*, which are left in the winding by reason of the projecting ferrules. Between these, draw the lines *d e*, which equals $\frac{1}{48}$ of the circumference of the armature, less the spaces *c c c c*, and between these the wire may be plotted out, and the number of layers deep and wide per coil ascertained. The length of wire that will pass closely around the iron core will represent the "least perimeter," and the length that would form the outermost coil, the "greatest perimeter," respectively 10·75in. and 14·25in., the mean perimeter being, therefore, 14·25 + 10·75/2 = 12·5in.

Now, by taking the external diameter of No. 16 B.W.G. cotton-covered copper wire, and plotting it out within the space *d e*, it will be seen that four layers deep and five wide can be easily wound, even with the characteristic slack winding of the amateur.

Then $5 \times 4 = 20$ (No. of turns).

$20 \times 12{\cdot}5 = 250$ (inches per division).

$250 \times 48 = 12{,}000$ (inches per armature).

$\frac{12{,}000}{36} = 333$ (yards per armature).

$\frac{333}{3} = 111$ volts (per 1,300 revs).

Which is near enough in all reason.

The next subject to be considered is the resistance of this conductor and its proportion to the external system, remembering that—

$$\frac{R}{r} = \frac{\text{work}}{\text{waste}} - \text{efficiency.}$$

Therefore it is highly important that r should be kept as low as possible.

The armature is divided, when running, into two portions by the brushes upon the commutator, hence one-fourth only of the total length should be taken in the calculation. A reference to the column A in the following table will provide a multiplier for ascertaining the resistance of the length of conductor :—

RESISTANCE PER YARD.

B.W.G.	A.	B.W.G.	A.	B.W.G.	A.
7	·0009	16	·0073	25	·077
8	·0011	17	·0092	26	·098
9	·0014	18	·0128	27	·120
10	·0017	19	·0175	28	·158
11	·0021	20	·0262	29	·183
12	·0026	21	·0302	30	·215
13	·0034	22	·039	32	·310
14	·0049	23	·049	34	·341
15	·0052	24	·063	36	·492

The resistance per yard of No. 16 B.W.G. is here shown to be 0·0073 ohm, therefore length of conductor × 0·0073/4 = resistance of armature, in *this* case 0·6 ohm.

There is an apparent increase in running that appears to be proportional to the speed, and is due to the "self-induction" of the armature,* as well as the inevitable rise in temperature when work is being done. In the present example, actual test has shown its value to be approximately 20 per cent. of the resistance when cold.

Using this value, the resistance to be calculated is 0·6 × 20/100 = 0·12 and 0·6 + 0·12 = 0·72 ohms.

Following out the calculation, we must deduct this resistance from the total R of 12·5 ohms, and thus obtain the external resistance, viz., 12·5 — 0·72 = 11·7 ohms. From this data we can ascertain the proportion of work done in the armature, and in the external circuit, the current now being $\frac{110(\text{E at terminals})}{11{\cdot}7\ \text{R}} = 9{\cdot}4$ ampères. Work done in armature = C^2/r where C is the current in ampères and r the resistance of the armature in ohms, therefore $9{\cdot}4^2 \times 0{\cdot}72 = 88{\cdot}36 \times 0{\cdot}72 = 63{\cdot}6$ watts, and the corresponding work in the external resistance, r, is $88{\cdot}3 \times 11{\cdot}7 = 1033$ watts, and the relation between useful work and waste at present stands thus:

$$\frac{\text{Useful work}}{\text{Waste}} = \frac{1033}{63{\cdot}6} = \frac{1}{16}.$$

Now comes the question of the loss by reason of the energy absorbed in magnetising the field magnets. Whether this be shunt or series, the result will be the same, since a given magnetic intensity must absorb a given amount of energy in producing it, either relying upon thick wire of low resistance, as in "series," or many turns of fine wire of high resistance, as in "shunt" wound fields. In the former case, the "ampère turns" are a given number, more current and fewer turns; and in the latter, exactly the reverse. Say, for example, that 10,000 ampère turns will produce a magnetic field of a certain intensity; and in one example by 100 ampères flowing round 100 turns, and in the other by 1 ampère flowing round 10,000 turns, the magnetic effect is practically the same, and the energy absorbed in producing it also equal in both cases.

---

* The writer has noticed a discussion in the pages of the "E. M." relative to the running resistance of an armature. When the machine is driven and the F.M. disconnected, there is no doubt an E.M.F. generated, either due to the residual magnetism of the field or the terrestrial magnetism. This may cause an apparent reduction of resistance. Be this as it may, the *ra* of an armature increases when the machine is doing work, and this increase varies with the speed and current through the outer circuit.

If the winding of the magnets is to be in "series," the resistance of the coils should be slightly less than that of the armature in this winding, say 0·6 ohms. Then the energy absorbed by the generation of magnetic intensity in the field will be $88{\cdot}3 \times {\cdot}6 = 52{\cdot}98$ watts, and this must be added to the previous figure corresponding to the armature, $52 + 63 = 115$ watts. Now the total energy expended in the dynamo, relative to the useful work, may be expressed thus:—

$$\frac{88{\cdot}3 \times {\cdot}1{\cdot}3}{88{\cdot}3 \times 11{\cdot}7} = \frac{114{\cdot}79}{1033}$$

$\frac{1}{9}$, or, in other words, 11 per cent. of the total electrical work is absorbed by the machine itself.

It is worth while to compare the results obtained by winding the field in "series" with the relative "shunt" winding. The formula used in estimating the resistance in ohms of the shunt is as follows—$r_1{}^2/r_a = r_s$ where

r_1 = external resistance
r_s = resistance of shunt
r_a = resistance of armature

Substituting the quantities known thus:—

$$\frac{11{\cdot}7^2}{0{\cdot}72} = 194 \text{ ohms}$$

actually reducing the effective external resistance by providing two paths for the current, the value of which is obtained by the formula

$$r_1 \times r_s / r_1 + r_s = R$$

and R is the actual effective external resistance. Substituting the quantities, we get

$$\frac{11{\cdot}7 \times 194}{11{\cdot}7 + 194} = 11 \text{ ohms}$$

Then, by Ohm's law, $E/R = C$, the total current flowing will be

$$\frac{110}{11} = 10 \text{ ampères}$$

respectively 0·5 amperes through the shunt, and 9·5 through the external circuit. Then

$$0{\cdot}5^2 \times 194 = 48{\cdot}5 \text{ watts expended in shunt}$$

and

$$9{\cdot}5^2 \times 11{\cdot}7 = 1055{\cdot}3 \text{ watts expended in external work,}$$

or

$$\frac{48{\cdot}5}{1055{\cdot}3} = \frac{1}{20}$$

or five per cent. of the useful work, and comparing this result with the "series" winding we get

$$\begin{array}{rl} \text{shunt} = & 48{\cdot}5 \\ \text{armature} & \underline{66{\cdot}5} \\ & 115{\cdot}0 \text{ watts expended in machine.} \end{array}$$

$$\begin{array}{r} \text{waste} \\ \text{useful work} \end{array} \frac{115}{1055} = \tfrac{1}{9} \text{ shunt winding,}$$

and

$$\begin{array}{rl} \text{“series”} & 52{\cdot}0 \\ \text{armature} & \underline{63{\cdot}0} \\ & 115{\cdot}0 \text{ watts expended in machine,} \end{array}$$

with, of course, approximately the same waste of energy compared to the output of the dynamo.

Before going into the details of the somewhat tedious process of winding the armature, it will be well to consider the lengths and resistances of conductor and fields for other purposes, as before mentioned, such as direct incandescence lighting, and charging accumulators.

Let it be assumed that the taped armature and bare field magnets are to be wound so as to light 20 incandescence lamps of 38 ohms working resistance, commonly called 50-volt lamps, each absorbing a current of 1·3 ampères, and, of course, coupled in multiple arc ("or parallel").

The external resistance due to lamps .... $\left.\right\} \frac{38}{20} =$ 1·9 ohms.

External resistance due to leads, &c., about $\frac{1}{10}$th of lamps .... $\left.\right\} \frac{1·9}{10} =$ 0·12 ohms.

Total external R = 2·09 ohms.

And current required for each lamp E/R=50/38=1·3 ampères, and for the whole circuit 1·3 × 20 = 26 ampères. Following this calculation in order to ascertain the E.M.F. required in the external circuit; again, by Ohm's law, R × C = E 2·09 × 26 = 54·34 volts. It must be borne in mind, when selecting a gauge of wire, that the current has a "heating" effect of 26 ampères in this case, and the wire must have sufficient area to conduct this without deteriorating the insulation, or greatly increasing its resistance by heat. The limit ought to be 2,000 ampères per square inch in machines of the construction that is here described.

CHAPTER III.

In a well-ventilated armature, where the mass of iron is in excess, and also laminated, and the field exceptionally powerful, there has been obtained a density of 2,570 ampères per square inch of conductor. Table II. gives a perfectly safe and efficient ratio, and also allows for the conduction and radiation of heat from the core; in the present instance, this is very slight.

The table is suitable *only* for armature densities, since in the closed coil ring armatures there are really two circuits in multiple arc:

TABLE III.

B.W.G.	Diam. inches.	Safe current.	B.W.G.	Diam. inches.	Safe current.
6	·203	120	14	·083	21
7	·180	97	15	·072	17
8	·165	86	16	·065	12
9	·148	72	17	·058	9
10	·134	58	18	·049	7
11	·120	43	19	·042	5
12	·109	36	20	·035	4
13	·095	27	22	·028	3

This table is for ampères safe current per gauge, for *armatures* only.

From the table here given No. 13 gauge of wire seems best suited for the armature. The first column of diameters shows that 4 by 4 layers may be allowed per coil, and the mean length or perimeter is known, viz., 12·5in. The calculations previously given suffice as an example without again detailing the process, therefore:

$$\frac{12{\cdot}5 \times 16 \times 48}{36} = 253 \text{ yards.}$$

and 253/3 = 82· volts at 1,300 revs. per min.

Upon referring to the resistance table, the running resistance of the armature will be *f*.

Upon referring to the resistance table, the running resistance of the armature will be 0·21 + 0·16, the allowance for heating, induction, etc., before mentioned, total 0·37 ohm.

The field magnet resistance, according to our previous formula, is, when wound in "series," about 0·3 ohm, making the total resistance of the machine 0·67 ohms. Now, we have seen that the *r* of the external or lamp circuit is 2·09 ohms, and therefore the total resistance is

$$2{\cdot}09 + 0{\cdot}67 = 2{\cdot}76 \text{ ohms.}$$

Then, by Ohm's law, we again find the E.M.F. necessary to force 26 ampères through the work,

$$2{\cdot}76 \times 26 = 71{\cdot}76 \text{ volts,}$$

therefore the calculated E.M.F. is ample for the work required, and the resistance of the machine is also within reasonable limits, and may be regulated by a simple adjustment of the speed.

Now, the ratio of the total work and that expended in the machine is

$$\frac{26^2 \times {\cdot}67}{26^2 \times 2{\cdot}76} = \frac{452{\cdot}9}{1865{\cdot}7}$$

or 25 per cent. of the *total* work is absorbed by the machine itself.

The size and number of turns of wire upon the field magnets may be calculated from the data that will supplied when the operation of winding them is described.

A machine of this pattern, exactly similar in size and construction, was lately made to charge 27 E.P.S. accumulators with a current of 12 ampères, and to be driven by a 1½-H.P. gas-engine, and since it has done good work the winding may serve as an illustration.

Gauge of wire on armature, 15 B.W.G.; length, 266 yds;

running resistance between brushes, 0·88 ohm; E.M.F., 88 volts; shunt-wound field magnets, 70lb. No. 18 B.W.G.; resistance, 35 ohms; exciting current, 2·5 ampères; speed, 1,250 revolutions per minute.

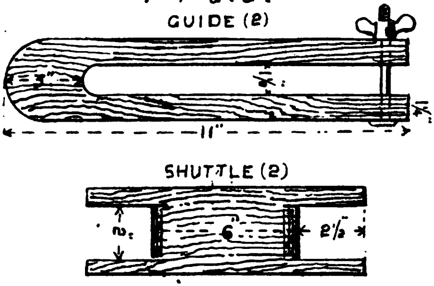
The "back E.M.F." of the accumulators is 27 × 2·2 = 59 volts; and as the E.M.F. at the terminals is 88 volts, it follows that 88 — 59 = 29 volts is the actual available electromotive force to overcome the resistance of the armature, leads, and cells, which is 0·88 + 0·81 = 1·69 ohm.

The peculiarity of this application of a shunt dynamo lies in this "back E.M.F.," which, according to the formula for finding the resistance of the shunt coils, $r_1^2 / r_a = r_s$. The "back E.M.F." must be treated as a resistance in the following manner. The E.M.F. of the machine is 88 volts, and when running at a rate of 1,300 revolutions per minute, it is *known* to give a current of 16 ampères through 27 cells; then, by Ohm's law 88 / 16 = 5·5, which is equivalent to 5·5 ohms total resistance. Then $5{\cdot}5_2$ / 0·8 = 34 ohms, the required resistance of the shunt coils. Properly calculating this, the resistance of the armature ought to be deducted from the total resistance; but as in this case there are frequently reasons why the resistance of the shunt should be slightly more or less than the exact calculation, according to circumstances, such deviations from rule will be made apparent when the winding of field magnets is treated in these papers.

We must now proceed with the practical work of winding the taped armature, having endeavoured to render the somewhat difficult question of the size and length of wire as clearly as possible. A piece of plank shonld be screwed to the ordinary work-bench in such a manner that two persons may stand, one on each side, to work, the armature being clamped down to the board by a wood clamp passed through the interior. The operator and his assistant thus face each other across the breadth of the armature core, as it were. The more skilful of the two, whom we shall afterwards describe as the "winder," stands in such a way that when winding he works from his side as the coils progress, from right to left, and the ends that are to be left for the commutator connections also terminate upon his side.

Now, two guides should be prepared of hard wood, having a stud and thumb nut for tightening upon the armature. These should *not* be thicker than the width of one coil, which is ascertained by reference to Fig. The shape of the guides is shown in Fig. 8.

FIG. 8.



The first thing to be done now is to place one of the guides across the core, against one of the joints (ferrule and stud) on winder's *right* side of the joint. A piece of wood of the exact width of the gap that will be left should be bradded to the guide in position, so that it will accurately fill the gap, of course temporarily, and the winding will commence from the winder's *left* of this. The other guide should be put in position, also to the winder's *left*, and a space left between the packing piece upon guide No. 1 and guide No. 2 equal to the width of one coil.

Two shuttles of hard wood, nicely rounded, a mallet, and a hard-wood wedge, with rounded and smooth edges and surface, now complete the winder's outfit.

Upon one shuttle should be wound, with a little to spare, the length of double cotton-covered wire that has previously been calculated for one coil; then, if the winding is to be four layers deep, four full perimeters of wire should be wound off upon the second shuttle. In describing this operation, in order to render the use of the two shuttles more clear to the amateur, the first, holding the bulk of the wire, will be termed No. 1, and the other with four layers upon it No. 2.

Beginning close to the packed guide to his *right*, the winder passes No. 2 through the armature to his assistant, who thereupon hangs a weight to it, and then he receives No. 1 from the winder *over* the top of the armature, passes it back to him *through* the interior, receives it again, and so on, straining tight each time, and bringing the strands level with the mallet and wooden wedge. A short piece of tape is laid upon each edge of the core, so that the last two turns pass over it, leaving an end of tape free when the other guide is reached. The last turn being laid close to the guide, the tape end is brought up between the wire and guide, then the first turn of the second layers is made by the assistant *over* the top with No. 1 shuttle, No. 2 remaining neutral all this time. The second turn of this layer should bind the tape end over the first, thus securing it from slipping when the guide is removed. Then a weight should be attached to No. 1 by the winder, while he gives the layer a good coat of shellac varnish. The tape ends should again be laid ready to bind in the last turn, and the winding proceed until one turn is required to bring the second layer close to the starting guide. Instead of performing this turn with No. 1, the winder hangs a weight to it when he receives it from his assistant at the finish of the last turn but one, and this final turn completed with No. 2 shuttle, which the winder passes back, and again receives from the assistant over the top, and returns *through* the armature, so that No. 2 makes the last turn of second layer and first turn of third, then is weighted by the assistant, and again remains neutral for a time.

The third layer now proceeds with No. 1 to the other guide, the last turn being taped as before, and the first turn of the fourth and last layer is begun with No. 1 shuttle, and wound until the last turn but one, when the assistant passes it *through* to the winder, when it should be nearly empty. No. 1 shuttle is then passed *over*, and completes the last turn, and with the end of wire from No. 1 and the end from No. 2 respectively, coming *through* and *over*, the winder pulls taut, and makes a neat and tight twist with the pliers, taking care to place some tape between the wires in case of a short circuit.

By this arrangement of two shuttles the final ends are brought out in the *last* layer, *over* and *under*, and the distortion and risk of short circuit consequent upon leaving the first end to protrude through the whole winding prevented.

The guides may now be removed, one only being required in the future, as the rigid wall of the first coil will form a sufficient guide for the second, and so on.

Each layer should be well coated with shellac varnish, and in the course of winding over the core, if at any part the tape insulation should seem insecure or abraded, a fresh piece may be stuck on with Prout's glue.

The whole armature is thus wound, each coil being a repetition of the first in every detail, care being taken that the *exact* length of wire be used on each, or there will be a considerable spark at the commutator when the dynamo is running.

The winder should also be especially careful to get the layers perfectly even and flat on the outer surface and ends of the armature. The interior necessarily differs, because the winding space is less, and the layers irregular in consequence; but this is out of sight, and, electrically and mechanically considered, is of little importance. The wheel ends may be temporarily put on, carefully bringing the ends of the coils through the arms.

Then put the spindle in, and key up, but not permanently, ready for running in the lathe. If the winding has been finished well, and the wheel-ends are a good fit, the whole armature ought to be true, and any slight irregularity may be tapped down with a wooden mallet, and the six gaps filled up with wood. Presuming that it is true, however, the next thing to be done is to "bind" the armature, so that the centrifugal force set up by its rapid rotation within the poles may not cause it to fly apart and be destroyed.

A strip of tape 1½in. wide is tightly bound round the centre of the circumference of the armature, and over this a strip of asbestos paper of equal width. Then a spool of No. 20 B.W.G. wire is placed upon a spindle behind the lathe, so that the wire will reel off freely. Ordinary copper wire is of no use for this purpose. The best material is phosphor bronze or Delta metal, both of which possess great tensile strength in proportion to the gauge.

Having put a carrier or driver upon the armature spindle, and put the back gear into action, the winder should take up his position behind the lathe, while his assistant prepares a soldering iron, resin, and solder. The winder then attaches the end of the wire to one of the projecting armature studs, and, beginning ⅛th of an inch away from the edge of the tape and asbestos band, he takes one turn of the slack wire round his mallet-handle, and his assistant starts the lathe with a slow speed. Holding a piece of emery cloth in his hand, the assistant guides the wire in regular, even turns, cleaning its surface at the same time, the winder meanwhile keeping the wire very tight by means of his hold upon the mallet-handle, and his foot being braced against the lathe-bed.

Directly the winding has reached to within ⅛th of the edge of the tape band, the lathe must be stopped, and the assistant must "sweat" the band together with solder, and so secure the end, the winder keeping the wire tight meanwhile. The free ends having been cut off close, the whole band must be "sweated" all round, using a *hot* soldering-iron, and plenty of powdered resin. The asbestos paper will prevent the tape or coils from being scorched.

The armature may now be removed from the spindle, and the wheel ends taken off, and preparations made for coupling the coils in "series." To do this the armature is laid upon the bench, with the wire ends uppermost, and then, beginning at any convenient coil, untwist the ends, strip and clean them down to within ¼in. of the coils. Repeat this operation with the next coil, then cut the four ends off exactly 2in. long, and take the *end* of the first coil and the *beginning* of the next, and twist these ends together (one twist only), bringing the rest of the 2in. length out straight, even, and close together, and then "sweat" them along their length with solder. Repeating this all round, the *end* of the last coil will join with the commencing end of the first, and the whole of the coils will be in "series," and 48 ends, 2in. long, will be ready for coupling to the commutator, each end being a double wire, sweated together. A couple of yards of gutta-percha tube should be obtained from any chemist, of the kind used for nursery bottles, and this may be cut up into 48 lengths of 1in. each. One of these pieces of tube should be threaded upon each connecting end of the coils, and pushed well down to the twist; also the whole of the twists should be well taped, by interlacing the tape between each connection over and around the end of the tube. As far as wiring and winding are concerned, the armature is now ready for the commutator, and after receiving a good coat of shellac varnish, should be placed to bake at a gentle heat for a day or two if possible.

When the varnish is perfectly dry, the 48 ends may be tested for continuity, by coupling one to a battery and galvanometer, and touching each one all round with the other end of the wire from the instrument circuit. If all is right, the needle will deflect each time. Now, without removing the wire that is coupled to one connection, touch all the six studs with the other: there should be *no* deflection if there is not a "body contact" between the iron core and studs, or wire and studs. It should be remembered that perfect insulation should be carefully attended to, as a short circuit in the armature, or a "body contact" will sure to partially, if not wholly, destroy it, when the higher E.M.F. of the machine comes into operation. In practice this test is made by sparking, without a galvanometer, and with an E.M.F. of 100 volts.

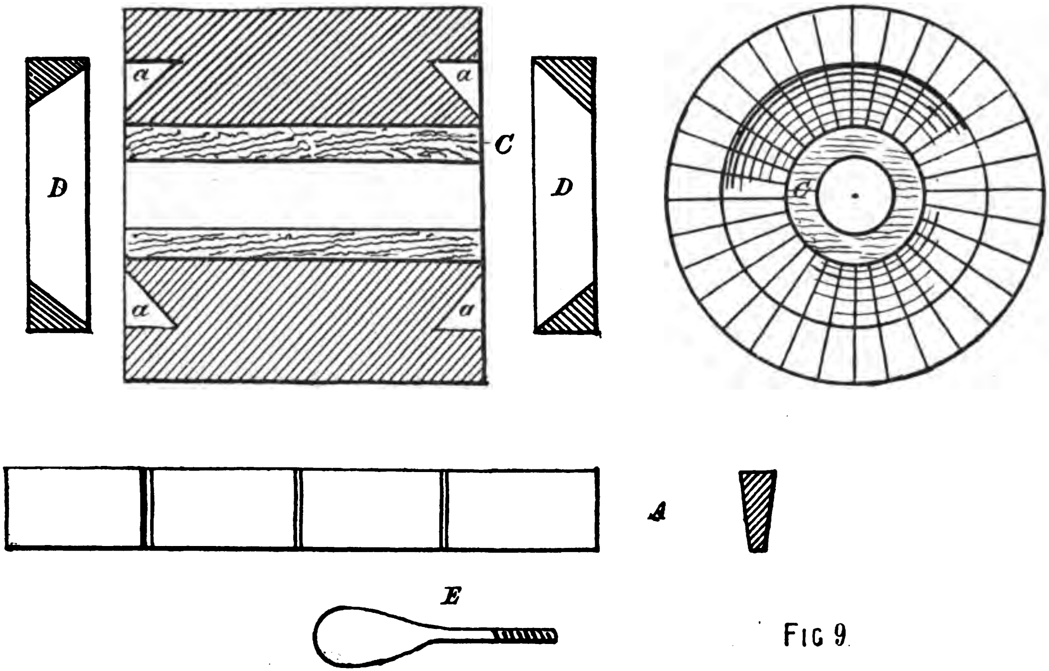


FIG 9

CHAPTER IV.

THE COMMUTATOR.

THE commutator next demands our attention, and its arrangement upon the spindle is shown in Fig. 10; also an end view of the segments after the building and turning has been finished, in Fig. 9 (purposely made on an enlarged scale). The first thing that has to be done is to make a pattern of the commutator strips, A, Fig. 9, and to do this properly a circle must be drawn, slightly larger in diameter than the finished commutator, and an inner circle smaller than the bore, to allow of the final tooling. Divide this circle into 48 divisions, great care being taken that the dividing be accurately performed. Then on each side of the pencilled dividing lines draw a parallel pair of lines to represent $\frac{1}{32}$in. of insulation strip between each bar. It must be remembered that in building up the commutator the intervening insulation does *not* taper towards the centre; therefore, to avoid a lot of filing, the parallel lines will commence $\frac{1}{64}$in. away from the dividing or centre line upon the outer circle, and run parallel right down.

To make the pattern, twelve slips of wood, A, Fig. 9, are cut, and planed off so that the section corresponds exactly with the division upon the circle. Each piece may be nicked on each side, to facilitate breaking off, and then should be sandpapered, so that there remain no rough edges to form an excuse for a bad casting.

The metal for commutators should be hard brass, or phosphor bronze if the latter is obtainable, for there is more wear upon this part of a dynamo than on any other, and certainly it is the most troublesome to replace.

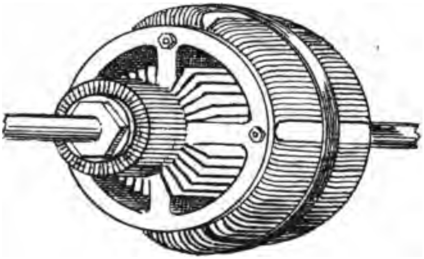
When the castings are finished and cut off at the nicks, the pieces should be pickled in brass finisher's "dip," to clean the sand and roughness from the surface, and then filed up if they require it. A sheet of asbestos millboard, $\frac{1}{16}$in. in thickness, must be obtained, and this should be chosen of a close grain, and clean, incisive cut. Mica is a better substance for this purpose, but is neither so cheap nor so easy to work as asbestos card.

Forty-eight slips may be cut rather larger than the commutator bars, and then placed in an oven, or similar apparatus, until all the moisture has evaporated.

A piece of iron, ¼in. thick and 2¾in. wide, must be bent round so as to form a circular cramp, having two lugs bent up, which are drilled and fitted with two ½in. bolts and nuts. When the cramp is drawn together so that the lugs meet, or nearly so, the internal diameter should be 5¼in., and the interior perfectly circular.

Slacking the bolts, and wedging the lugs apart, the strips may now be placed inside, with a slip of asbestos card between each, and when the whole of them are thus arranged, any distortion of the circle near the lugs of the cramp may be rectified by driving wooden packings between the cramp and commutator while screwing up. Even if the distortion seems beyond rectification, there is hope, for the turning will bring the whole into proper shape, if it is not too bad to allow of cleaning up.

FIG. 10.



The commutator is now ready for the lathe, and should be fixed to the face-plate by the cramp, bored out to receive the wooden bush C, Fig. 9, and the angular recess *a* turned in the face, which may be skimmed up as far as the cramp will allow. This recess *a* is made to suit the gun-metal rings D, and should be quite a loose fit, all edges avoided, and nicely rounded off. Turning the commutator round upon the face-plate, a turned ring should be interposed so that this second chucking should be true with the first. The facing should this time be to size, and be carried, as before, as far as the cramp will allow; the recess will be similar to the other, and then the commutator will be ready for fixing upon the spindle. Now, taking the spindle, run the end nut off, and thread upon it one of the rings D, then a large washer of calico (unbleached), then a similar one of asbestos paper, then another calico, then asbestos and calico washers again, and then the commutator with the cramp still upon it, taking care that none of the turnings, or metal dust, are interposed anywhere. The wood bush C is, of course, driven into the commutator previously. Then the alternate calico and asbestos washers are repeated, the second ring D, and the end nut, which must then be screwed up hard, forcing the insulation washers of calico and asbestos into the recess, and allowing the rings D to draw the commutator bars tightly to the shaft without making metallic contact. The end and back nuts on the spindle should be so arranged that when the end one is screwed hard up its exterior face will form a shoulder for the journal; then, putting the spindle between centres in the lathe, the commutator may be turned over the top (taking the cramp away), the sides faced down, and just finished with a second-cut file and quick speed. Heavy cuts should never be put upon a commutator, neither in boring nor turning, for if it does not actually shift it, there is considerable risk of doing so.

The next thing is to test the bars individually for a possible "short-circuit." Sometimes this may occur through a little piece, or pieces, of turning dust getting imbedded in the asbestos insulation, and so putting the two bars in metallic contact. In practice this is frequently "blown out" by a high E.M.F. which is used for testing; but this is not a safe proceeding, nor are the appliances ready to the amateur's hand as a rule; so a careful inspection, and any metal dust picked out with a sharp scriber, will doubtless remove the fault.

The asbestos insulation, which was $\frac{1}{16}$in. in thickness, will now be found to be $\frac{1}{32}$in. only on account of the pressure, and the exclusion of the moisture with which it is always surcharged when delivered from the warehouses, as it will, when large surfaces are exposed to the air, take up a quantity of water.

Care should be taken not to trim off the edges of the calico and asbestos washers too close to the rings, as it will frequently draw in and cause a "short-circuiting," or else a "body contact."

After testing the commutator again for the latter (which is a serious misfortune, if it occurs, because the cramp must be replaced, the commutator taken off and examined, and it will inevitably require turning again when replaced) the connectors, E, Fig. 9, will be the next piece of work.

These connectors, 48 in number, are made of 12 B.W.G. bare copper wire, and are cut off 2in., flattened and screwed at the ends, as shown. A small ladle should be put upon the fire, and some hard solder melted in it, and two gallipots placed handy, one containing "dipping acid," or spent nitric, and the other chloride of zinc, or, as it is usually called, "soldering fluid," or "killed spirits of salts."

Holding the screwed end of the connectors by means of a pair of pliers, dip the flat part into the "dipping acid," wipe, then into the chloride of zinc, and thence into the melted solder. By this method the connectors are readily "tinned" for soldering. With the commutator upon the spindle in the lathe, a slight mark should be made all round, $\frac{3}{16}$in. away from the armature end. A fixed scriber will do this effectually.

Upon this line a centre dot should be marked in the centre of each bar, and a tapping hole drilled $\frac{3}{8}$in. deep, and to suit the above connectors in each end, all round, care being taken to keep the line of the drill radial with the commutator centre, so as not to drill through into another bar.

Before screwing the connectors in, however, the armature must be put in position upon the spindle, and the wheel end that comes next to the commutator should have all its inner edges nicely rounded, and a broad ring of vulcanised fibre $\frac{1}{32}$in. thick cut to go between it and the armature coils, to prevent any possible body contact. The coil ends should be neatly parted off into six sets of eight in each, so as to pass through the spokes of the wheel end. These wheel ends should not be tightly screwed up to the armature body until they are in position upon the spindle, and keyed up permanently. Then the ends of the studs may be cut off and trimmed up, and slightly burred to keep the nuts from working loose. The coil ends are carefully bent so that they do not press hard against the wheel end, and the whole placed in the lathe. The connectors are now screwed in, each with its flat against a coil end, then spinning the whole against a fixed scriber; they should be slightly bent back, so as to give them a *convex* appearance when running, and set perfectly true, and cut off uniformly. Every connector is now turned over its adjacent coil end, and closely nipped round it, and, as both are well tinned, the joint is easily "sweated" with plenty of resin and a hot iron. A little touch of zinc white improves the appearance of the connections, and sets off the whole armature. The latter may be covered over and laid aside until the field magnets are wound and the brush-holder finished.

CHAPTER V.

BRUSH-HOLDER.

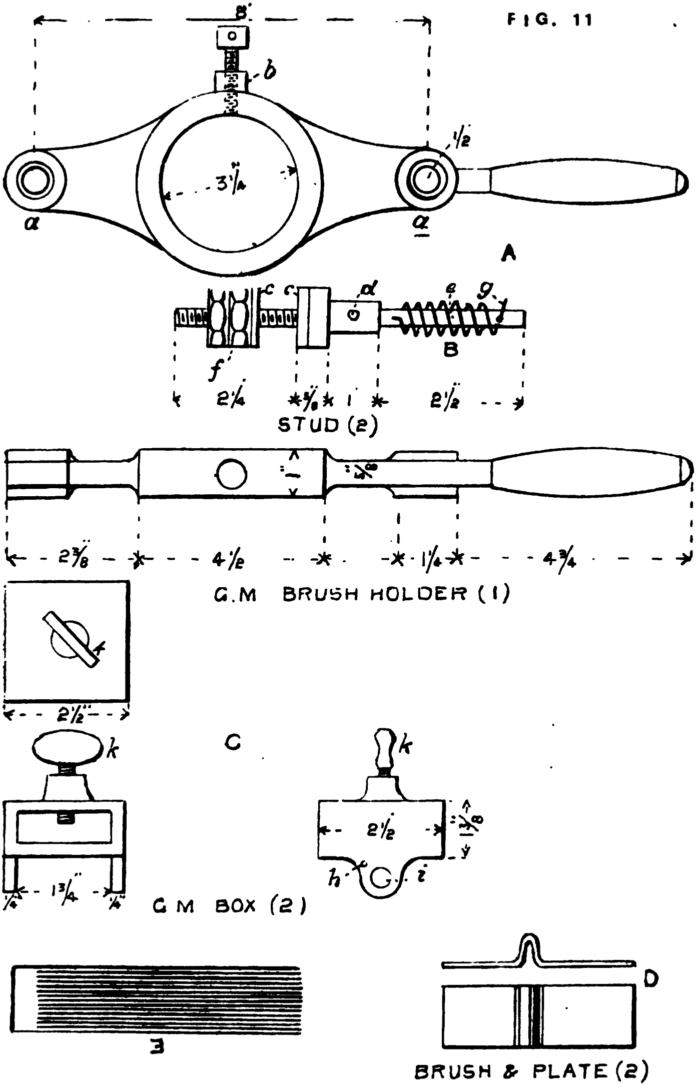
THIS is shown in detail on Fig. 11, A being plan and elevation of the holder proper. The centre is bored out to fit the boss K of the bearing end D, Fig. 2, and a small boss is provided at *b* for a set-screw, so that the angle of the brushes may be kept when once adjusted. The holes *a a* are drilled ⅝ clearing, in order that a strip of 1/16in. vulcanite fibre may be warmed and bent to form an insulating bush for the screwed end of the studs B, which are provided with vulcanite washers, *c c*, to complete the insulation of each stud. These studs are fitted with two hexagon nuts, *f*, one for tightening the stud upon the holder, and the other free for attaching the connecting wire, which should be turned and flattened.

A small hole at *d* is drilled for the convenience of holding the stud by means of a "tommy," while the nut is tightened. Another hole at *g* is for the purpose of holding the end of the tension spring *e*. The brush box is shown at C, Fig. 11, and its shape and fitting need no explanation further than that *i* is drilled half clearing, to fit upon the studs B, and *h* is a small hole for receiving the other end of the spiral spring *e*. A small fly-screw K tightens the brush E, the plate D intervening, and rendering the pressure uniform over the brush.

The brushes may be made of No. 20 B.W.G. copper wire, cut off to length and straightened, then clamped in a box, leaving about ½in. projecting, which may be cleaned in "dipping acid," and tinned by the method recommended for the commutator connectors.

These wire brushes should be about 3/16in. thick, and a band should always be placed round the end to prevent the brush

FIG. 11



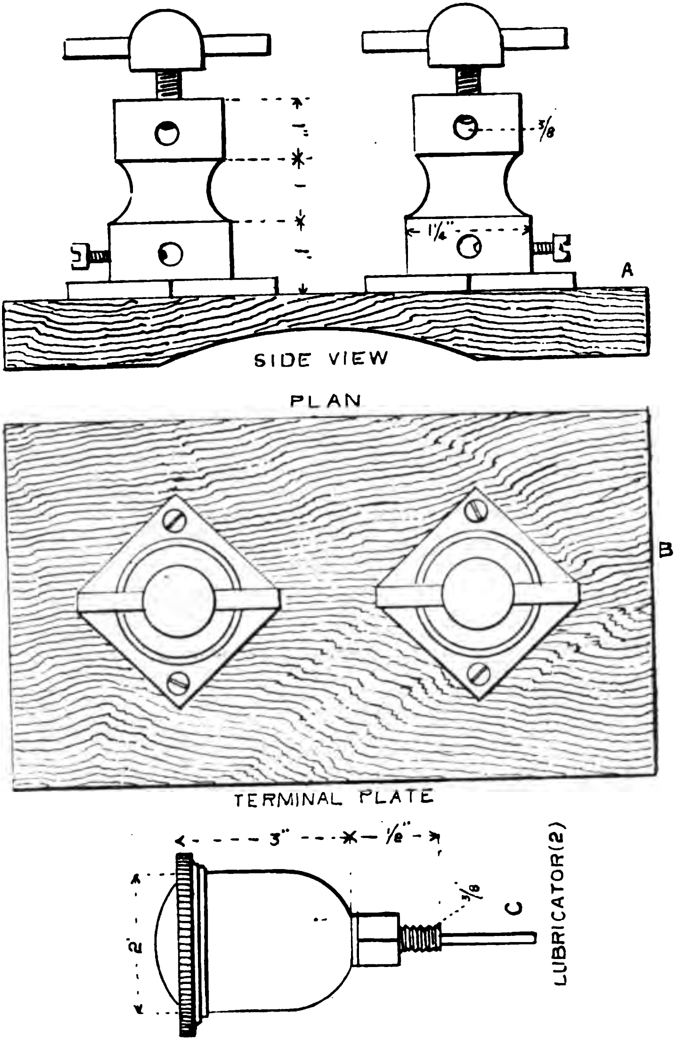
STUD (2)

G.M BRUSH HOLDER (1)

G M BOX (2)

BRUSH & PLATE (2)

FIG. 12.



from straggling and doing mischief. Some electricians prefer brushes made of copper stencil plate, in successive layers, and such brushes certainly have one advantage over the wire ones, in that the surface of the commutator is kept much more true in running.

TERMINALS.

The terminals upon their plate of polished wood (A and B, Fig. 12) give quite a finished appearance to the dynamo, if they are well made. The holes and screws in the base of the terminals are for the purpose of coupling the brush connections, which should be of stout wire, bent symmetrically, and well taped. If the machine is to be shunt, or compound wound, a third hole and screw must be fitted on the base, and these may be smaller, because the wire held by them is invariably finer.

A dynamo fitted with a scanty pair of terminals always presents the appearance of scantiness, and the machine suffers in the estimation of every expert before they have an opportunity of judging by its efficiency.

The amateur has a wide field before him when selecting a lubricator; but for appearance and utility the style shown at C, Fig. 12, will probably suit his purpose best. The milled cover unscrews, of course, and the needle should fit well, and an oil that is too fluid should never be used, because the draught from the armature drives a spray in both directions if the flow be too free. Long bearings, like those designed for this amateur's dynamo, wear very slowly, despite the high speed, with just enough lubrication to maintain the film, and no dirt. A very slight "end play" should be allowed, say $\frac{1}{16}$in.; it allows the commutator to wear without ridging, and assists lubrication of the bearings, and keeping the armature cool very materially.

WINDING THE FIELD.

The field magnet casting must be put in the lathe, utilising the centres before mentioned; then a good coat of shellac varnish should precede a layer of stout brown paper; then the ends of vulcanised fibre, which, being slit, may be sprung over the cores. These ends should be cut larger than the iron projections cast upon the magnets, so that the wire is never dangerously near the iron. Three thicknesses of $\frac{1}{32}$in. fibre for each end and one of brown paper; then the whole may be coated with shellac, and the core wound with two layers of unbleached calico, again varnished, and left to dry.

In the case of a series-wound machine, a groove, or chine, should be chipped so as to allow the wire end to pass up the cheek of the pole-piece without distorting the coils, and a guttapercha tube slipped over it. When winding a shunt machine, it is better to bring a thicker wire out for the connections, for there is no remedy for a broken wire but entire rewinding.

Having in this way prepared for the wire that is to be laid on, the next operation is to calculate how much and of what gauge it is to be, having already ascertained the required resistance by the methods previously explained.

In the construction of a dynamo, the field winding is the most difficult of all the calculations: the formulæ which apply to it are full of co-efficients, thus rendering them useless for amateurs; therefore, as the object of these papers is to simplify these calculations, even at the expense of the fractional part of volt or ampère, the rules given are simple, so that the amateur may work out his own winding for whatever purpose he intends his dynamo.

For elliptical cross sections of F.M. core, as in the present instance, *the depth of the coil of wire should be rather less than* $\frac{3}{4}$

of the conjugate (or lesser) axis of the ellipse, which may be represented by the multiplier 0·7. This applies to both shunt and series winding, for, as stated before, for coils of the same depth, but of varying resistances, the portion of the total electric energy used in magnetising the cores is equal, or nearly so.

The elliptical section of core here is—

(I.) Transverse axis = 3·25in.
Conjugate axis = 2·00in.

Then the area is 3·25 × 2 × ·7854 = 5·1 square inches, and the depth of wire 2 × 0·7 = 1·4in. Now, the weight of wire of any gauge that can be wound to the aforesaid depth must be roughly ascertained before the right gauge can be chosen to suit the calculated resistance. A method described by Mr. J. T. Sprague ("Electricity: its Theory, Sources, and Application") is here slightly modified to suit the present circumstances, as follows:—

Find the area, in square inches, of the ellipse formed by the wire when wound on to a depth of 1.4in.

(II.) Transverse axis 3·25 + (1·4 × 2) = 6·3in.
Conjugate axis 2·0 + (1·4 × 2) = 4·8in.

Then 6·3 × 4·8 × ·7854 = 23·7 square inches, from which must be deducted the area of the iron core 23·7 — 5·1 = 18·6 square inches.

Then, multiplying by the length, 7in., we get the solid content of the wire coil in cubic inches, 18·6 × 7 = 130·2 cubic inches.

Now, to obtain this in pounds of copper wire, a multiplier must be taken which represents the weight of a cubic inch of copper in decimals of a pound, and at the same time allows for the cotton covering and the rotundity of the wire; these multipliers may be thus expressed—

(III.) From 6 B.W.G. to 10 B.W.G. = 0·21
„ 10 „ „ 14 „ = 0·20
„ 14 „ „ 16 „ = 0·195
„ 16 „ „ 20 „ = 0·181
„ 20 „ „ 22 „ = 0·174

Now, suppose that the present dynamo is to be shunt wound, and the resistance of the armature, its E.M.F., and the external resistance of the circuit are known, and the problem remains for solution—(1) the resistance of the shunt; (2) the weight and gauge of wire; (3) the work done in excitation.

CHAPTER VI.

WE must assume that the E.M.F. is 60 volts, actual r_a of the armature 0·3 ohm, and external circuit r_1 is 4 ohms. Then by the formula, $r_1^2/r_a = r_s$. Substituting the known values, $4^2/0{\cdot}3 = 16/0{\cdot}3 = 53$ ohms.

Then, choosing a wire gauge between 16 B.W.G. and 20 B.W.G., where the constant is ·181, the known solid content in inches of the coil must be multiplied by it, 130·2 × ·181 = 23·4lb., and referring to the wire table (Table III.) for ohms per pound, No. 18 B.W.G. will be found to suit the requirements, the resistance being 0·57 ohms per pound. 23·4 × 0·57 = 13·3 ohms, and since there are four coils, 13·3 × 4 = 53·2 ohms, which is the required r_s If, on the contrary, we suppose the same dynamo to be series wound, the total resistance of the field r_m will be 0·24 ohm, and a wire must be selected to carry 15 ampères without heating, which must necessarily happen if the depth and resistance are not kept to their proper ratio. Now, choosing a wire from 6 B.W.G. to 10 B.W.G., we find the weight to be 130·2 × 0·21 = 27·3lb., and taking No. 6 B.W.G., where the resistance is ·0021 ohm per pound, we obtain 27·3 × ·0021 = ·057 ohm, and for the 4 coils, ·057 × 4 = ·228 ohm, which is near enough for all practical purposes. But such stout wire as No. 6 is extremely difficult to wind on account of its thickness, so a wire of less diameter may be chosen, and the field magnet circuit coupled with the right and left pair of coils in multiple arc, thus dividing the total resistance. For instance, take No. 10 B.W.G., where the resistance is ·01 ohm per lb.—27·3 × ·01 = ·273 ohm, the resistance of one coil, and ·273 × 4/4 = ·273, the resistance of the two in parallel, which is near enough.

Now, to ascertain the number of ampère turns in these examples, it is necessary to divide the depth of the coil by the diameter of the wire over the insulation; thus, in the shunt winding, the diameter of 18 B.W.G. is ·056in., so that—1·4/·056 = 25 layers deep, and 7/·056 = 125 layers in length, so that each coil has 125 × 25 = 1,125 turns.

The E.M.F. is 60 volts, and resistance of the shunt 53 ohms, so that the exciting current will be 1·1 ampère; therefore the number of ampère turns will be 1125 × 1·1 = 1237·5 ampère turns. Now, comparing this with the last example of series winding—viz., No. 6 B.W.G.—and the diameter of No. 6 being ·22in., 1·4/·22 = 6 layers deep; 7/·22 = 31 layers in length; 31 × 6 = 186 turns per coil. Then with armature resistance ·3 added to the magnet coil resistance ·22, and external circuit 4 ohms, makes a total R of 4·52 ohms. Now, 60/4·52 = 13 ampères, and 186 × 13 = 2418 ampère turns per coil.

WIRE TABLE.—III.

Number.	Inch diameter over insulation.	Yards per pound.	Yards per ohm.	Ohms per pound.	Pounds per ohm.	Safe current.	Multiplier per cubic inch.
6	·221	2.67	1330	.0021	497·4	60	0·21
7	·213	3·39	1046	·0032	307·8	48	
8	·182	4·04	879	·0046	217·3	43	
9	·166	5·02	707	·0051	140·6	36	
10	·150	6·13	580	·0105	94·5	28	
11	·135	7·64	465	·0165	60·8	21	0·20
12	·122	9·26	383	·0241	41·3	18	
13	·119	12·2	291	·0418	33·8	13	
14	·098	15·9	222	·0718	13·9	10	0·195
15	·085	22·3	158·3	·1424	7·	8·5	
16	·076	26·0	136	·1918	5·23	6	
17	·068	32·7	108	·3013	3·31	5	·181
18	·059	45·8	77	·5715	1·69	3	
19	·050	62·4	57	1·095	0·92	2·5	
20	·043	89·8	50	2·273	0·44	2	
22	·033	140·4	25	5·549	0·18	1·5	·174

All these calculations will serve the purpose of the amateur, and assist him to determine the gauge, weight, &c., of wire to produce a certain result; but, as all the resistances are taken from table, and considering that the wire manufactured by different makers varies considerably, it will be well for him to procure a table from the particular maker who supplies him with material. He may also test the resistance per foot, yard, or pound with a Wheatstone bridge.

Another method of increasing resistance is to pass a current of known quantity through the wire, and test the potential at terminals, when $\frac{E}{C} = R$; but this necessitates the use of a good voltmeter and ammeter. However, by the simple rules given here, the amateur may calculate his winding so as to get the required result with the least *effective* weight. The first step in obtaining the depth of the coil forms a basis to work upon, and is not intended for the purpose of founding a new theory of winding dynamos, and the general rules given here have been the result of experiment and practice.

Presuming that the wire has been chosen and obtained, and is double cotton covered, and of good quality, we may proceed with the winding. The wire should be placed upon a drum or spool, which may be braked, so that it does not revolve too freely, and so get the wire tangled. The winder will again stand behind the lathe, unless he reverses the motion by crossing the belt. He will guide the wire while the lathe goes at a steady speed, and his assistant will tap the wire flat and even with a mallet and wooden wedge. Each layer should receive a coat of varnish or Brunswick black.

The winding should *commence* on each coil close to the pole-piece, and a length of stout wire, say No. 14 B.W.G. if the machine be shunt wound, or No. 7, should be soldered to the starting end, well taped, insulated with tube inside the coil, and then placed within the groove cut in the iron for it. Then the winding may go on, always finishing at the *under* side of the upper magnet, at the farthest end from the poles. The other magnet is commenced in the same place—viz., nearest the pole, but finished off on its upper side, opposite the pole. With this method of ending and finishing the coupling up is easy. Suppose that the dynamo is fitted up, then couple the *commencement* of the top left-hand coil to the nearest terminal, then the *termination* of No. 1 coil to the *termination* of lower left-hand coil No. 2. Then bring the *commencement* of No. 2 across to the *commmencement* of the lower right-hand coil No. 3, the *termination* of which couple to the *termination* of No. 4, the *commencement* of which couple to the other terminal, if a "shunt" machine, and if wound in "series," of course, one end will be attached to one brush-holder, while the other will be coupled to the opposite terminal.

The winding of the field magnets should be carefully performed, or the effect of the machine may be marred. Nothing looks worse or more unworkmanlike than a bad and irregularly wound coil. When wound and coupled up, the field magnets must be tested for polarity, which is done by means of an ordinary shilling compass, taking each half of the field at once, right and left, not top and bottom. Taking top commencing wire, say mentally, "*enter*," then take the *commencing* wire of the bottom coil, and say "*leave*," and couple one to carbon and the other to zinc of the battery, taking care to note which is which, since where you have disconnected the two right and left halves at the bottom, the *leave* wire of the one will be the *enter* wire of the other half to produce the same polarity.

Having tested the polarity, the whole dynamo may be touched up and nicely painted, and placed on the foundation that may have been already prepared, and the belt adjusted to the proper degree of tightness and the power applied. If the dynamo be shunt-wound, the magnetism of the field will commence immediately; but if, on the contrary, it be a series-wound machine, the external circuit must be closed before the magnets can be acted upon. If a voltmeter and ammeter are to be borrowed or hired, get them ready for testing away from the influence of the magnets as far as possible; then test your machine for E.M.F. (if shunt-wound) with the circuit open and current passing round the shunt coils; then $E/C = R$ in ohms of shunt. Test speed. Then put the full load of lamps on the machine, put the ammeter in circuit, and test current strength and E.M.F. in volts at the terminals again. The difference in E.M.F. represents that factor of the energy which is absorbed by the machine itself.

Now vary the load, and notice the behaviour of the machine, whether an alteration of the angle of the brushes is an improvement or a decided disadvantage. Test the speed again, which should be tolerably constant if the motive power be suitable for the work. If the speed falls when the load is on, the loss of E.M.F. will be attributable to the driving power, and not the dynamo.

Every part of the frame of the machine should be tested for leakage; but since such leakage may result from defective insulation in the external circuit, they should be tested separately, allowing the current from the machine to pass through a temporary resistance during the test.

The brush-holder should be brushed carefully all over each day to prevent the metal dust from the commutator from bridging across the insulating washers and causing leakage.

No dynamo, whether it be shunt or series wound, ought ever to be short-circuited; but in the latter case the danger of total destruction is greater; therefore it is a good plan to introduce a "cut-out" in the F.M. circuit, which will melt and open the circuit if the current be excessive. A strip of lead, clamped between two sets of brass bars, which are connected to the wires, will suffice. The commutator must never be "oiled"—a touch with an oily rag being sufficient lubrication.

APPENDIX.

FIELD MAGNETS.

It is evident that the same armature can be fitted to various types of field magnet, always provided that the bore of the polar cylinder bears the same relation to the diameter of the armature, and that the magnetic intensity be duly maintained.

Under these circumstances, the shape of the field may be varied according to the amateur's convenience, without impairing the efficiency of the machine.

In the accompanying plate several forms of field magnets, with attachments, are shown.

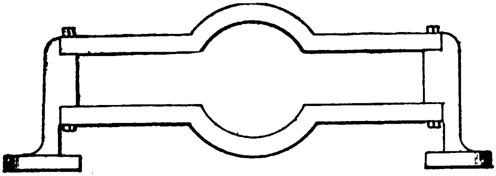


Fig 1

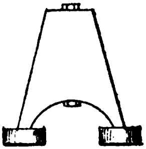


Fig 2

Fig. 1 represents two bars of wrought iron A A, which are shaped so as to bring the bore as true as possible, and are then bolted upon the cast iron ends B B, as shown in the end elevation Fig. 2.

Fig. 3 represents another method of constructing a wrought iron field, where the pole-pieces B B are of cast iron, and are bolted to stout plates of wrought iron A A, which form the field magnet cores, and are again bolted to the bearing ends C C, which are of cast iron, and carry the lugs for bolting the machine upon its foundation.

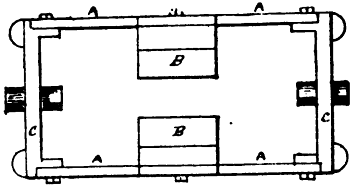


Fig 3

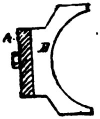


Fig 4

Fig. 5 shows a front elevation of a very compact form of field, specially designed for the "Xero" armature by Mr. H. Jones, of Lambeth. In this case the bobbins form the cores, and are remarkably easy to wind, and the tooling is reduced to a minimum. A A are the pole-pieces, B B the bobbins, which are cored throughout to admit of the bolts being freely passed through B B.

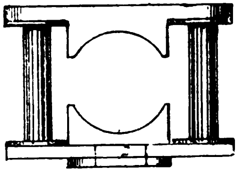


Fig 5

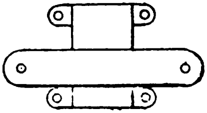


Fig 6

Fig. 6 shows the lower pole-piece A, which carries a T-shaped bed-plate cast upon it, which is fitted to the two brackets C C.

Mr. Jones also slightly modifies the winding of the armature, as he winds the coils separately upon a mandrel, taping and insulating as he goes, and then slips them upon the built armature, removing one stud at a time for the purpose. In designing a field magnet for a dynamo, the main object to be kept in view is to make the yokes and poles sufficiently massive, and to use perfectly soft iron. The residual magnetism should be of the faintest intensity, and if wrought iron can be used to form the cores, it is decidedly advantageous to do so, since the efficiency of the dynamo may be materially increased.

SECONDARY BATTERIES.

A comparatively small dynamo may be arranged to light a greater number of lamps by the use of an accumulator than could be obtained from the machine direct, in this manner.

Suppose that the output of the machine is 60 volts × 30 ampères, = 1,800 watts, which is equivalent to about 720 candle power, say 36—20 c.p. incandescence lamps. This light will be required each evening for, say, five hours—making a total of 180 ampère hours, when running direct from the dynamo. Now, suppose that the dynamo is used to charge an accumulator of 25 cells for 10 hours, at a rate of 30 ampères. The cells in this case receive a charge of 300 ampère hours, and presuming that they will return 80 per cent. of the original charging current during the five hours of discharge, this represents 240 ampère hours, or 48 lamps for five hours instead of 36.

The greatest advantage in the use of secondary batteries is found when the number of lamps is very small, and the dynamo need only be used for charging, say, twice a week, or under circumstances where the motive power is running daily, the machine may be constructed for an output of a few ampères only, sufficient to maintain the charge in the cells.

It is an erroneous, but common, supposition respecting the secondary battery, that it is capable of STORING ELECTRICITY. It certainly absorbs and stores *energy*, which is electrically transferred to it, but as the charging current enters at the +

terminal of the accumulator and leaves at the — terminal, it is evident that no storage of the subtle element CAN take place, even were such storage possible. The result of the passage of a current of electricity through a liquid is to decompose that liquid into its constituent gases, which in the case of a secondary battery, where the liquid between the plates is dilute sulphuric acid, is *oxygen* and *hydrogen*. In this manner, by the passage of a continuous current the + plate or plates become oxidised, and the — plates similarly hydrogenised, the capacity of such oxigenation being equivalent to the storage capacity of the secondary battery. When pure lead is employed for the electrodes the process of oxidising is very slow, before an appreciable return can be obtained, and the cells have to be frequently *reversed* in charging, making the — terminal the + or entering terminal, and *vice versa*. The object of this is to render the + plates spongy by hydrogenising them, so that the degree of oxigenation may be greater at the next reversal, and the capacity of the cell increased.

This tedious process is termed "forming," and is calculated to exhaust the patience of any amateur. However, when completed, the accumulator so made is more satisfactory than when an oxide is used in the form of a paste. Red lead, or litharge, are the usual oxides of lead that are employed, and is pressed in the form of paste into a grid, or frame, and several of these arranged alternately, and coupled in parallel within a suitable trough or water-tight box, form one cell. The storage capacity depends upon the immersed area of the lead surface, and the internal resistance is reduced by placing the plates closely together, using strips of glass, vulcanite or rubber to separate them.

By thus obtaining an oxidised and spongy surface to start with, the process of forming is considerably curtailed. When an accumulator has become completely discharged, the re-charging will scarcely produce a visible effect, save that the liquid may be slightly disturbed; but when the storage capacity is nearly attained, bubbles are freely given off, and accompanied with the copious evolution of gas, with the distinguishing smell of hydrogen. A discharged accumulator should be immediately re-charged, and never left for any length of time discharged, because the sulphate of lead formed by the action of the sulphuric acid in the liquid upon the non-active surface is injurious to the life of the accumulator, and also renders it difficult in re-charging. The base of each cell should be kept dry; in fact, the whole accumulator should stand in a tray, with proper drain pipe provided, and each cell be raised above the tray by glass rods, or small cups like the sound insulators on the legs of a pianoforte.

The specific gravity of the liquid should be kept up to the mark, viz., 1·150, or, roughly, ten parts water to one of acid.

ELECTRO-PLATING.

The dynamo used as a generator is invaluable to the electroplater, superseding the cumbrous and wasteful primary batteries, the fumes of which are as injurious to health as the cells are troublesome and costly to manage.

For amateur work generally, a very small machine will suffice, the range of E.M.F. being from ·5 to 6 volts, and the current, of course, being proportionate to the work to be done. The internal resistance of a plating machine must be low, and the field magnets should be shunt or compound wound so as to prevent a reversal, which would inevitably spoil the work.

Copper requires from ·5 to 1·5 volts E.M.F. to deposit it.

Silver from 1·5 to 2·5 volts.

Gold from ·5 to 2 volts.

Nickel from 4 to 6 volts.

Respecting current required, the following table will show the weight of metal deposited by one ampère of current in one hour:—

Metal.	Grains per hour.	Ampères per ounce per hour.
Copper	17	28
Silver	60·4	8
Gold	110·3	4·5
Nickel	16·7	30

And, of course, the density of the current must be regulated to suit the work in hand, resistances being interposed between the dynamo and the bath, so that the current strength may be regulated to a nicety.

The dynamo should be so wound with reference to the internal resistance, that the maximum current is suitable for a full bath, when the cathode presents the greatest surface.

If the magnets be properly compounded, the intermediate resistance may be dispensed with.

ARC LAMPS.

For the illumination of large workshops, or public buildings, the arc system of electric lighting is at once better and cheaper than a similar installation of incandescence lamps with the same total candle power. This system is not capable of the same distribution of light as when incandescence lamps are used, but the candle power per horse power of energy is considerably higher.

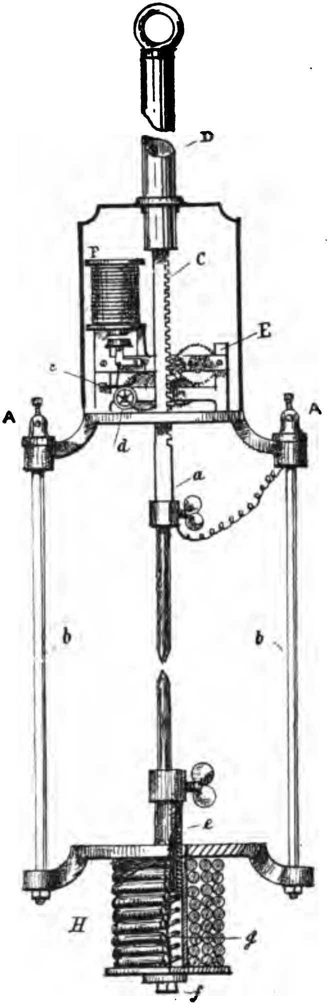
For instance, approximately, 250 candle power of incandescence lamps requires one horse power, but a single arc lamp of 1,000 candles requires the same amount of energy only.

As an approximation of the illuminating power of the electric arc, we may assume a circle of floor space 1,500 feet in area, which will be perfectly illuminated by a lamp of 1,000 candle power, 15 feet high. That is, the space occupied by a cone, with a base 45 feet in diameter and its apex 15 feet in height, would be well lighted by such a lamp. Small arc lamps seem to be impracticable for continuous lighting, and, in fact, amateurs do not, as a rule, seem to favour the system at all. It will not be, however, out of place in this small work to give a description and drawing of a lamp, the mechanism of which is extremely simple, and quite within the means of the amateur electrician. It is designed for $13^{\text{m.m.}}$ carbons, and has been proved by long use to be very steady in its action. In the accompanying sketch, A represents a cast iron base-plate, carrying a pair of insulated rods, *b b*, which form the + and — pole of the lamp respectively, and supporting the lower plate, B, at their lowest extremity.

C is a toothed rack, within a tube D, in which it can move freely. E is a common clock movement, with the escapement and hour-hand attachment removed. Upon the main arbor of this movement is fitted a pinion, gearing into the rack.

The latter is fitted with a carbon holder *a*, and so freely arranged that it can descend by its own weight, revolving the clock movement in doing so. The escapement wheel *d* will, of course, revolve at a high speed, and the pinion gearing into the rack proportionately slow, by which arrangement the feed is gradual.

A strip of steel, *c*, presses up against the escapement wheel *d*, and at its normal tension prevents the descent of the rack and upper carbon. An electro-magnet of high resistance, F, is arranged to draw the iron armature, G, towards it when a current passes round its coils, and G is coupled to the brake, *c*, by means of a light wire rod. In this manner, when the resistance of the arc becomes much too high, by reason of the burning away of the carbon, the magnet, F, becomes excited and draws the armature, G, and also the brake, *c*, thus liberat-


D
F
C
E
c
A
A
d
a
b
b
e
H
g
f

ing the escapement wheel, *d*, and allowing the upper or + carbon to descend.

As the resistance of the arc becomes less, the power of the magnet, F, decreases, and the brake again acts by its own tension and stops the revolution of the wheel, *d*, and the further descent of the carbon. The solenoid, H, carries as a core a tube, *e*, which is suitably arranged to hold the lower or — carbon. This tube slides upon a brass rod, *f*, forming a guide, and the spiral spring, *g*, tends to keep the tube and carbon elevated. The solenoid, H, is wound with thick wire of low resistance, and the *whole* current of the circuit passes round this, as it is placed in "series" with the arc. The magnet, F, of high resistance, is coupled as a "shunt" to this solenoid.

Directly the current is switched on and the two carbons are touching, the magnetic effect of the solenoid, H, depresses the — carbon by drawing the tube, *e*, within itself against the tension of the spring. In this way the electric arc is established, and should it be broken while the lamp is in operation, it is immediately re-established by the release of the tube, *e*, and its depression again directly the arc is re-formed.

I represents a small switch, which cuts the lamp out, in order to allow of adjustment without danger. Arc lamps are generally coupled in series, and the type here referred to is arranged for a current of from 10 to 15 ampères, where the total resistance of the lamp is from 4 to 4·5 ohms.

So we find that the E.M.F. required when the resistance of the solenoid and arc is 4 ohms, and the current 13 ampères—

$$4 \times 13 = 52 \text{ volts,}$$
$$\text{and } 52 \times 13 = 676 \text{ watts,}$$

which must be allowed for as the energy expended in maintaining the light.

LEADS.

The leads used for conveying the current from a dynamo should be of such sectional area as to offer a negligible resistance when the line is short. The insulation should also be fairly thick, and the staples used should not be driven in so as to cut through and make electrical contact with the wire.

Small cleats of wood, with two grooves about 1 or 1½ inches apart, and a wood screw in the centre, are preferable to staples when running the leads, and certainly the installation presents a neater appearance.

Leads should never be fastened near to gas or water pipes, and if the whole can be cased in, it is better to do so than to leave them exposed. There is a special moulding made for the purpose, which may be gilded or stained and varnished, thus adding to the appearance of the room or workshop, and enables the leads to be examined at any time. All joints should be soldered with resin, the ends of the wire being previously tinned by dipping into nitric acid, and after washing, plunging into melted tin. This is about the quickest method of tinning stranded cable, where the interstices between the wires cannot be properly cleaned by scraping.

Switches in the main circuit should be massive at the contacts, and fusible cut-outs provided throughout the circuit, especially close to the dynamo.

These may be simply made by two metal plates screwed to a pair of rigid plates upon a neat base-board. These plates form a pair of clips, which hold sufficient lead, or white metal foil, to carry the maximum current. The foil may be trimmed off until the current perceptibly raises its temperature, and then it may be relied upon to break the circuit if the current be greatly increased.

MOTIVE POWER.

Most amateur electricians find a great difficulty in providing a suitable source of power for driving a dynamo, a steam engine, with its boiler, and the necessity for constant attendance and supervision, being out of the question in many cases, and water power is seldom available and never practicable in large towns and cities, while the force of the wind is too uncertain, and the smallest apparatus of too cumbrous a character to render its utilisation as a motive power successful. Nor has the gas engine yet fulfilled the sanguine expectations that were rife at an early period of its career, the price being yet beyond the means of the average amateur.

Hot air, or caloric engines, are, as a rule, very large and very expensive as regards the first cost, in comparison with the power developed.

Probably, the best motor for domestic purposes is a small atmospheric engine, which is really a condensing steam engine, where the steam pressure only slightly exceeds that of the atmosphere, and the boiler and furnace being both self-feeding, require no attention for several hours.

We may reasonably expect something in the future from small petroleum engines as domestic motors, if the prices are within reason.

There can be no cheaper or better source of power than a stream of water, and the fortunate possessor of one upon his grounds is to be envied, if it be capable of developing useful power.

To gauge a stream approximately, a planed board should be placed across and pressed into the soil, so that the water flows over the edge, which must be set level. The board should be plugged all round with clay, to prevent any flow of water, save over the edge. Now take a piece of cork, and, going back in the direction of the source of the stream to a measured distance in feet, throw the cork in, and time its velocity in feet per minute till it reaches the board. Then take the width of stream at the board in feet, and depth of water, from the planed edge of the board to the surface in decimals of a foot.

Then, let d = depth on board in feet.
„ w = width at board in feet.
„ v = velocity in feet per minute.
„ C = cubic feet per minute.

$$d \times w \times v = C,$$

and where H represents the head of water, or height in feet from the dam to the tail race of the proposed wheel or turbine,

$$C \times H \times \cdot 001872 = \text{approx. H.P.}$$

Overshot water-wheels and breast-wheels require a considerable head of water, but their efficiency as compared to undershot wheels requiring less head of water is more than double.

As a rough guide for estimating the required area for the sails of a windmill, considering the velocity of the wind to be equivalent to a smart breeze, 12· square feet per horse power.

The writer saw a windmill a year or so ago driving a shunt-wound dynamo, which was used for charging accumulators, and an automatic cut-out was interposed to prevent the discharge of the cells through the dynamo during the fluctuations of the wind current.

The diameter of the sails was about 7 feet, and there were about 12 or 14, and he believes the power developed upon the countershaft was 1½ H.P. with a moderate breeze.

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